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THIS REPORT SUMMARIZES WORK PERFORMED UNDER THE ABOVE TITLED GRANT NO. AFOS4-87-0338 NAMELY, A STUDY OF TRANSPORT ASSISTED OPTICAL NONLINEARITIES IN CDTE AND THE FABRICATION OF AN OPTO-OPTICAL BEAM DEFLECTOR USING THIS EFFECT. A STUDY OF ORGANIC NONLINEAR OPTICAL MATERIALS USING DFWM AND THEIR APLLICATIONS TO OPTICAL INTERCONNECTS.

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INTRODUCTION

This report covers the period from October 1, 1987 through September 30, 1988, the first year under the contract. The objective of this effort is to define and evaluate new approaches to two-dimensional arrays of reconfigurable optical interconnections for optical computing. The emphasis is on optically-controlled optical beam directors or switches which can be fabricated into high density 2-D arrays. The proposed applications in optical neural computers and other types of optical computers require reconfiguration speeds on the order of microseconds. The emphasis is therefore on devices and nonlinear optical materials with response times of microseconds but with the potential for high packing density.

The approach to this research has two components:

i. nonlinear optical materials;

ii. optically controlled optical switching devices which can be integrated into 2-D arrays.

The materials work stresses the transport assisted optical nonlinear materials[1] since this is the only class of materials which exhibit a sufficiently large nonlinearity, in the response time required, and with a relatively low optical energy required. In these materials, optically excited electric charge is separated by an electric field to create a space charge field which reduces the total electric field. The change in the field effects the optical properties of the material by effects such as the electrooptic effect or the quantum-confined Stark effect. In many cases this is a broad band effect which can be used in the infrared where diode laser sources exist. This broad class of effect has already had a major impact in two of its forms: photorefraction and the SEED effect.

A figure of merit[2] can be defined, n^3r/ε, where r is the electrooptic coefficient and ε is the relative dielectric constant, which gives a relative measure of the change in the index of refraction per photon absorbed. We are working with two of the materials with the highest figures of merit and therefore with the maximum potential: CdTe(n^3r/ε=16.0 pm/V) and organic molecules(n^3r/ε=133 pm/V for MNA).

Our work on field shielding in CdTe is the first demonstration of a transport assisted approach which makes full use of the potential of CdTe. We have demonstrated optically controlled switching in the IR using this effect and are now working toward array integration.

The organic materials offer an enormous amount of diversity and therefore have an enormous potential in the field of nonlinear optics.[3] However, to date, there has been a relatively small number of applications of these materials. We have initiated a materials study under this program with the goal of using the transport assisted concept with organic materials.

For opto-optical switching applications, a third order nonlinearity is required where the index of refraction is a function of the optical intensity. Several organic materials exhibit a third order effect such as saturation in dyes and charge movement along polymer chains. However, these materials are either too slow (milliseconds) or have a very small nonlinear effect (10^{-9} esu). On the other hand, a second order (electrooptic) effect has been observed in aligned organics such as MNA which is large enough to be of device interest. Combining the second order effects with the transport assisted concept to create an effective third order effect is a very promising approach.

We have initiated a new component of this program to study techniques to incorporate MNA in sol-gel and polymer substrates. These molecules must be oriented and aligned as the substrate solidifies to achieve the full nonlinear effect. Approaches to use the transport assisted optical nonlinearity in these materials is under study.

RESEARCH PROGRESS

Field Shielding Nonlinearity in CdTe

Field shielding can be used to achieve optical switching, optical self switching, and optical limiting. The optical switch, which is shown in Figure 1, makes use of photoconductivity and the electro-optic effect. In CdTe, with an electric field along the <111> direction, the electro-optic birefringence can be observed by a signal beam propagating perpendicular to the applied field. A control beam perpendicular to the signal beam is at a wavelength at which the material exhibits modest photoconductivity. The photo charges created by the control beam drift into the dark region of the crystal where they are trapped and create a space charge electric field which is opposite to the applied field. Thus, in the absence of the control beam, the signal beam polarization is altered by the applied field and the beam is deflected by the prism into output 1. When the control beam is present,the field seen by the signal beam is decreased and all or part of the signal beam is deflected into output 2. For optical switching, the intensity or the wavelength of the signal beam is such that the signal beam itself creates little or no photo charge. For self switching and optical limiting, the control beam is absent and the signal beam is of sufficient intensity to switch itself.

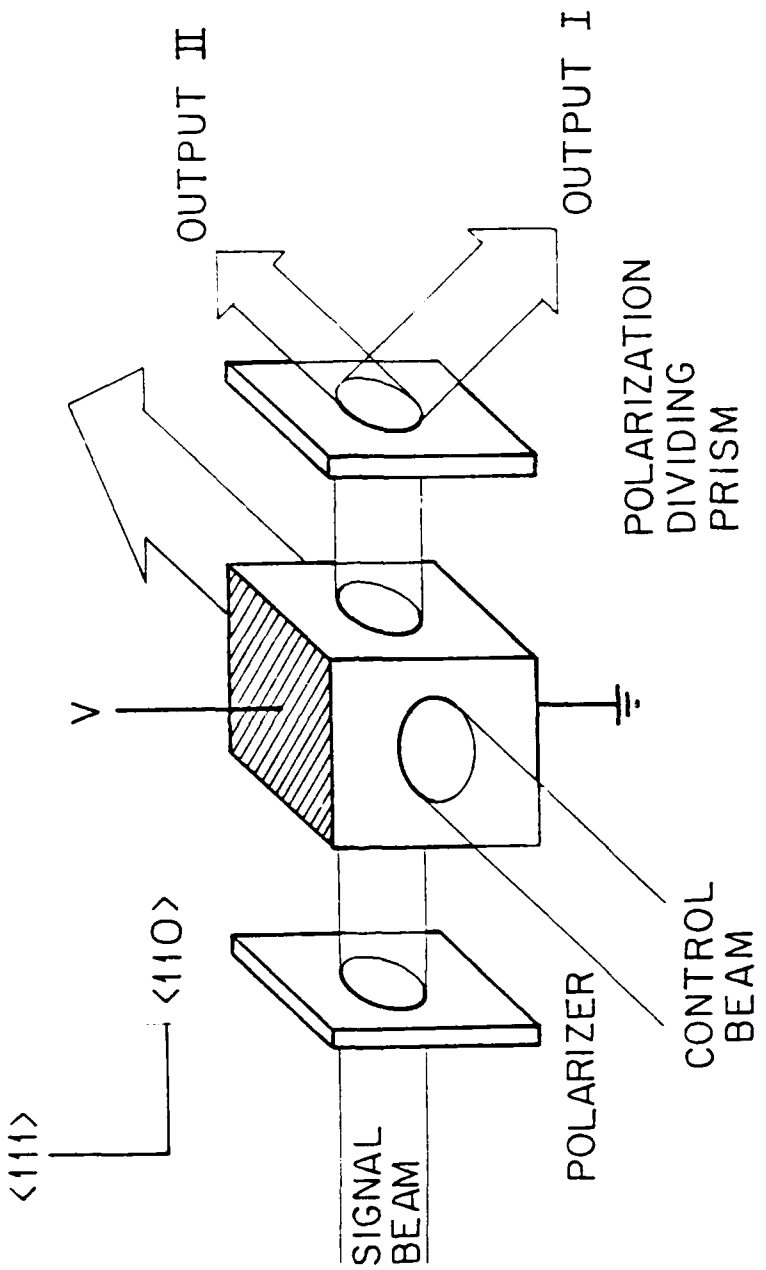


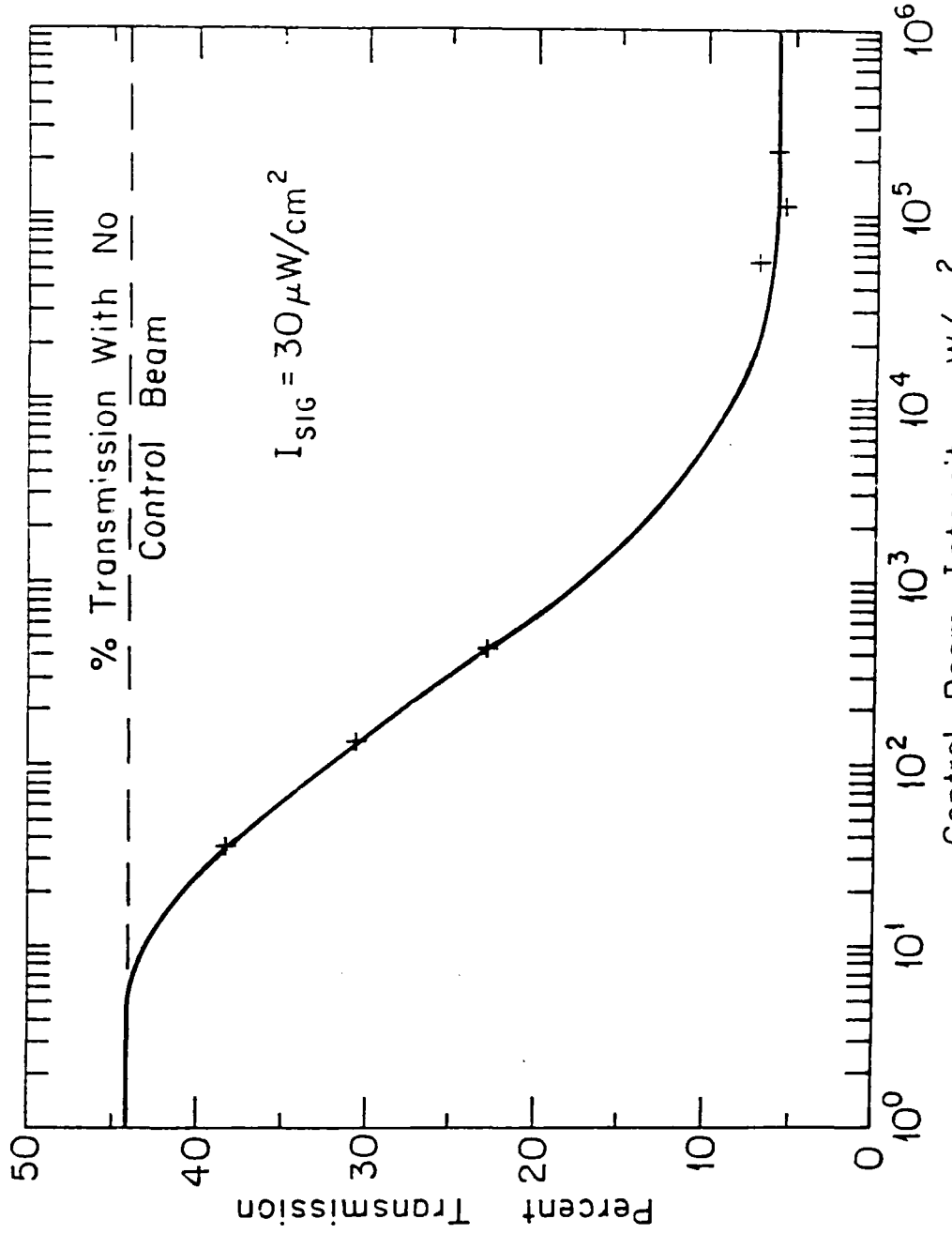
FIGURE 1. Opto-Optical Switch in CdTe

We have completed a series of experiments to demonstrate the switching which are reported in detail in Publications 8, 9, and 10. In these experiments, a 4 x 5 x 6mm^3 sample was used. The photoconductivity, σ, was measured as: $\sigma=5x10^{-10}+10^{-6}I$ (W-cm)$^{-1}$, where I is the intensity in W/cm^2 at 1.06 μm. Assuming unity quantum efficiency, this gives $\mu\tau_0= 3.2 \times 10^{-6}$ cm^2/V where μ is the electron mobility and τ_0 is the conduction band lifetime. The electric field was along the <111> direction (6 mm dimension) and the 1.06μm signal beam propagated along the <110> direction (5 mm dimension). The 1.0 mm dia. signal beam was polarized at 45° to the <111> direction. In some cases, silver paint electrodes were used and in others deposited gold electrodes were used. The control beam was also at 1.06μm and was unpolarized. The control beam was large enough to flood the sample or could be apertured to a 1 mm wide slit as suggested by Figure 1.

Figure 2 shows the steady state transmission of the switch as a function of the intensity of the control beam when the control beam flooded the sample and 3000 V was across the crystal. The signal beam intensity was held at 30μW/cm^2, which our earlier work showed creates negligible photoconductivity.

To measure the switching time, the control beam was pulsed by a fast rise (150 nsec) acoustooptic modulator. Figure 3 shows the switch turn-on time as a function of the control beam intensity. The switching time is proportion to I^{-1}; 10 W/cm^2 is required for a one microsecond switching time. This is the time for the charge pattern to form and is consistent with the grating formation times observed for photorefraction in semiconductors.[4] The switch turn-off time is limited by the time required for the trapped charge to be thermally excited from the traps. This is typically a few milliseconds in the dark and could be significantly reduced by flooding the CdTe by an erase beam.

The switch can be used to select pulses from a train of optical pulses as shown in Figure 4. The signal beam has been modulated by an acoustooptic modulator into a train of pulses of 365 microsecond duration. A 1.5 msec control pulse deflects two of the signal pulses totally into output 2. The switching time was 5μsec for the control beam intensity used. Following the end of the control pulse, the switch recovers in approximately 5 msec as the trapped charge is reionized by thermal effects . We have also demonstrated the selection of pulses from a train of 1 microsecond pulses.



Steady state signal beam transmission as a function of the control beam intensity . Signal beam intensity fixed at $30\frac{\mu W}{cm^2}$ and V=3000V.

FIGURE 2. Steady State Signal Beam Transmission As a Function of the Control Beam Intensity

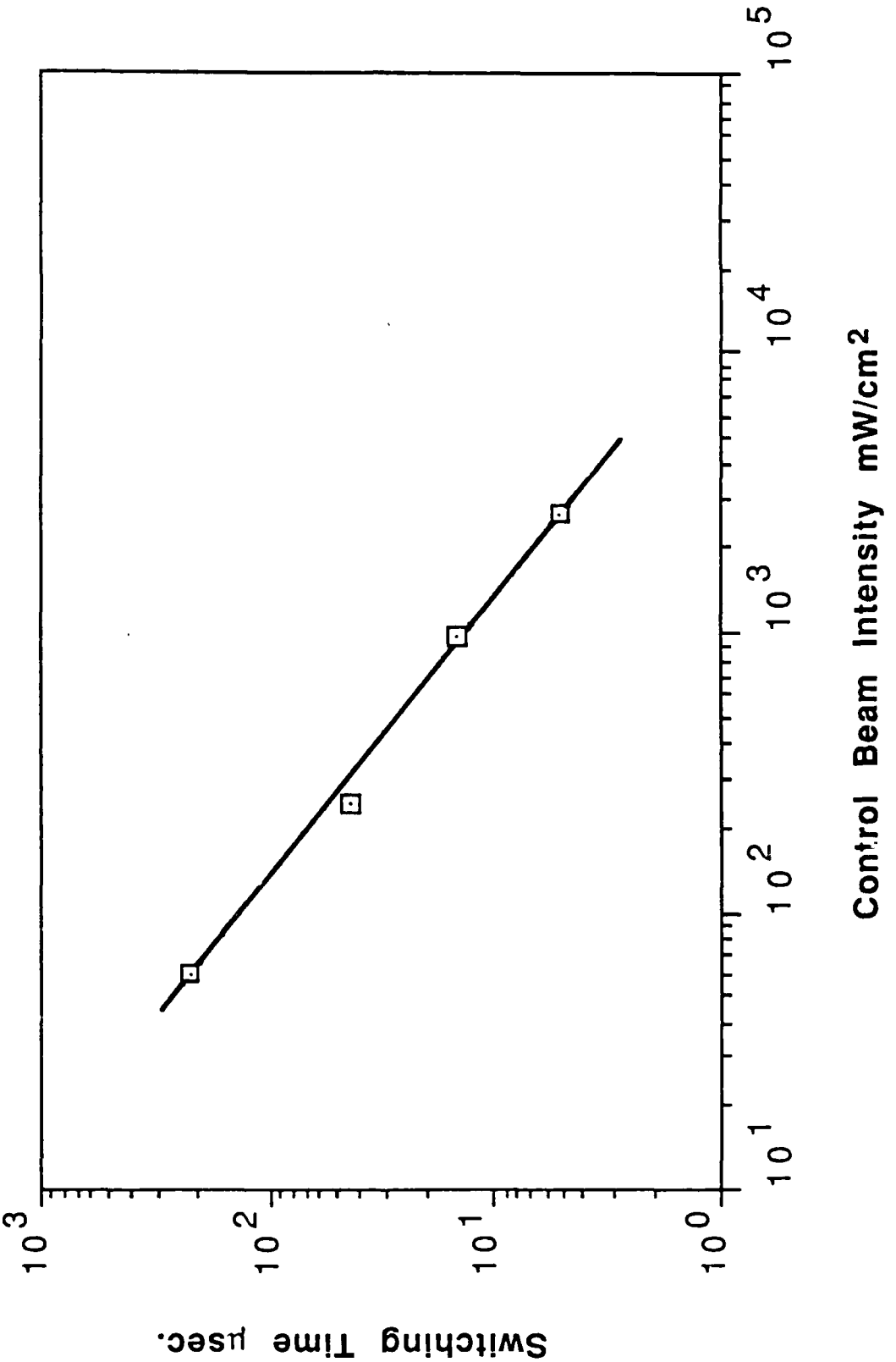
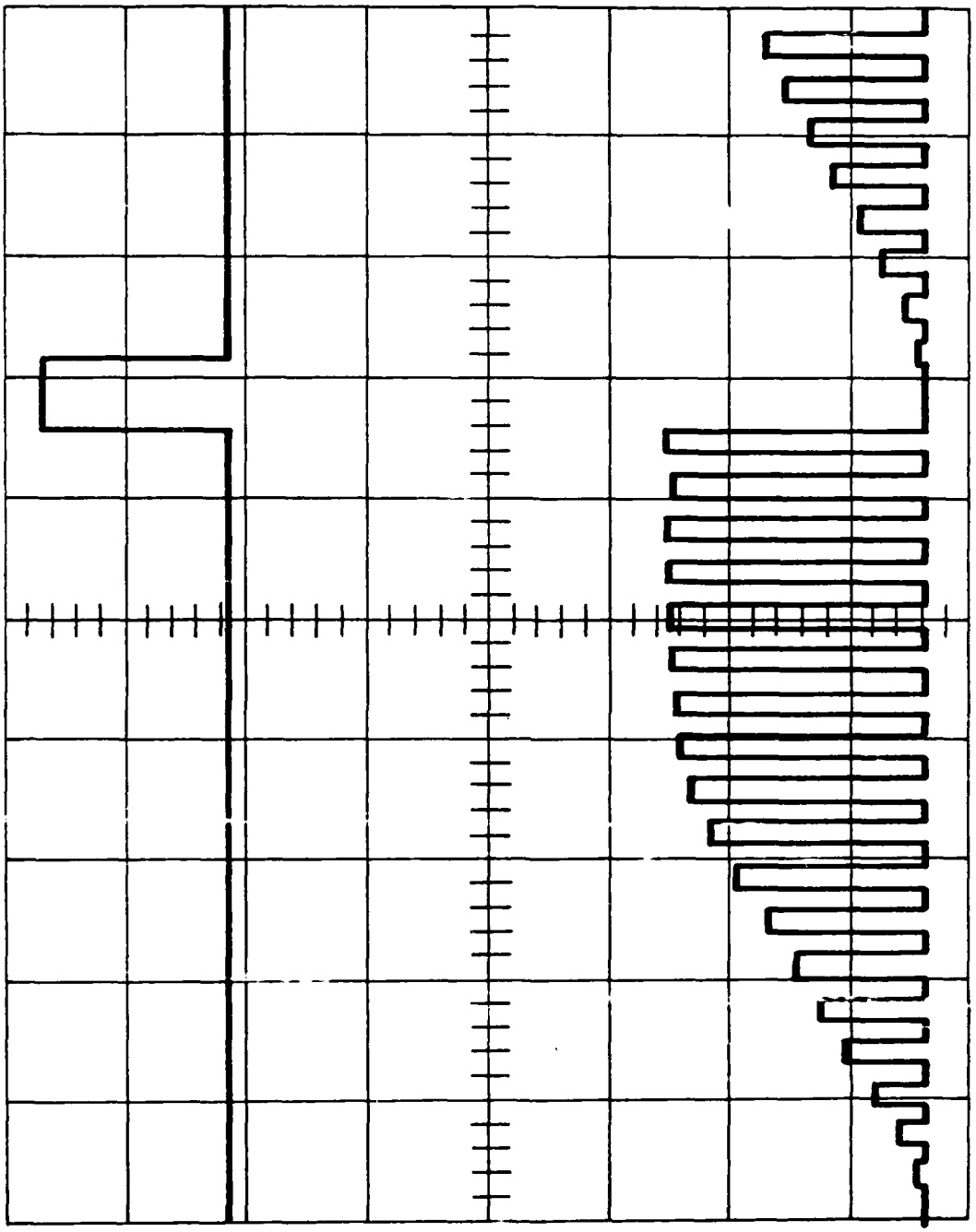


FIGURE 3. Switching Time Vs. Control Beam Intensity



Selection of signal beam pulses by a control beam pulse. Upper trace: control pulse. Lower trace: signal beam in output 1. Horizontal scale: 2.0 msec/div.

FIGURE 4. Selection of Signal Beam Pulses By a Control Beam Pulse

The properties of the switching action can be summarized as follows:

A. Minimum control beam intensity for switching - 1.0 milliwatt/cm^2.
B. Switching speed - 1.0 μsec at 10 W/cm^2 control beam intensity.
C. Useable wavelength range - 0.9 to 1.4 μm.

In the steady state, the control beam decreases the electric field seen by the signal beam; however, a transient during which the electric field increases, has been observed at the onset of the control beam. The amplitude of the transient signal pulse, which is largest when the control beam is near the positive electrode, indicates that during the transient the electric field seen by the signal beam is up to twice that given by dividing the voltage by the electrode spacing. The observed pulse width was approximately 100 microseconds when the control beam intensity was 1 W/cm^2, and its width decreases as the control beam intensity increases.

We believe this pulse is due to a domain of high field strength which moves between the electrodes. Current oscillations and moving field domains have been observed in other high resistivity semiconductors with deep level traps and have been attributed to the electron capture coefficient of the traps increasing with the electric field[5]. We also observe a pulse in the photo current corresponding approximately in time and pulse width to the signal pulse. The signal beam diameter was 1 mm and therefore a 100 microsecond pulse implies a domain velocity of 10^4 mm/sec. For comparison, if the data on domain velocity for GaAs of Rajbenbach et al[6] is linearly extrapolated to 1 W/cm^2, it predicts a domain velocity of 2.5 x 10^3 mm/sec.

Organic Nonlinear Materials and Devices

Experimental work to date has concentrated on the study of dye molecules in polymer matrices, using the technique of degenerate four-wave mixing (DFWM). In particular, we have examined fluorescein and acridine orange in such polymers as polymethyl methacrylate (PMMA), polycarbonate and polyvinyl alcohol. These dyes have the advantage of a very high $X^{(3)}$ (due to saturable absorption), which allows DFWM using a CW Argon laser. The major disadvantage is their relatively slow response time, ~ msec. This type of system does, however, have device promise: optical bistability using nonlinear absorption has been predicted and has recently been observed using fluorescein.[7]

A more fundamental problem in this type of materials system is bleaching of the dye after a few minutes of exposure to the laser. We have found that this bleaching is accompanied by the formation of two holographic gratings, defined by

the intersecting pairs of beams in the DFWM configuration. The detailed mechanisms involved are unclear, but a possible explanation is excitation of the dye molecule to a higher triplet state, leading to fragmentation. There is some evidence that the matrix into which the dye is incorporated has some bearing on this effect, and this is currently being investigated.

FUTURE RESEARCH DIRECTIONS

Field Shielding Switching

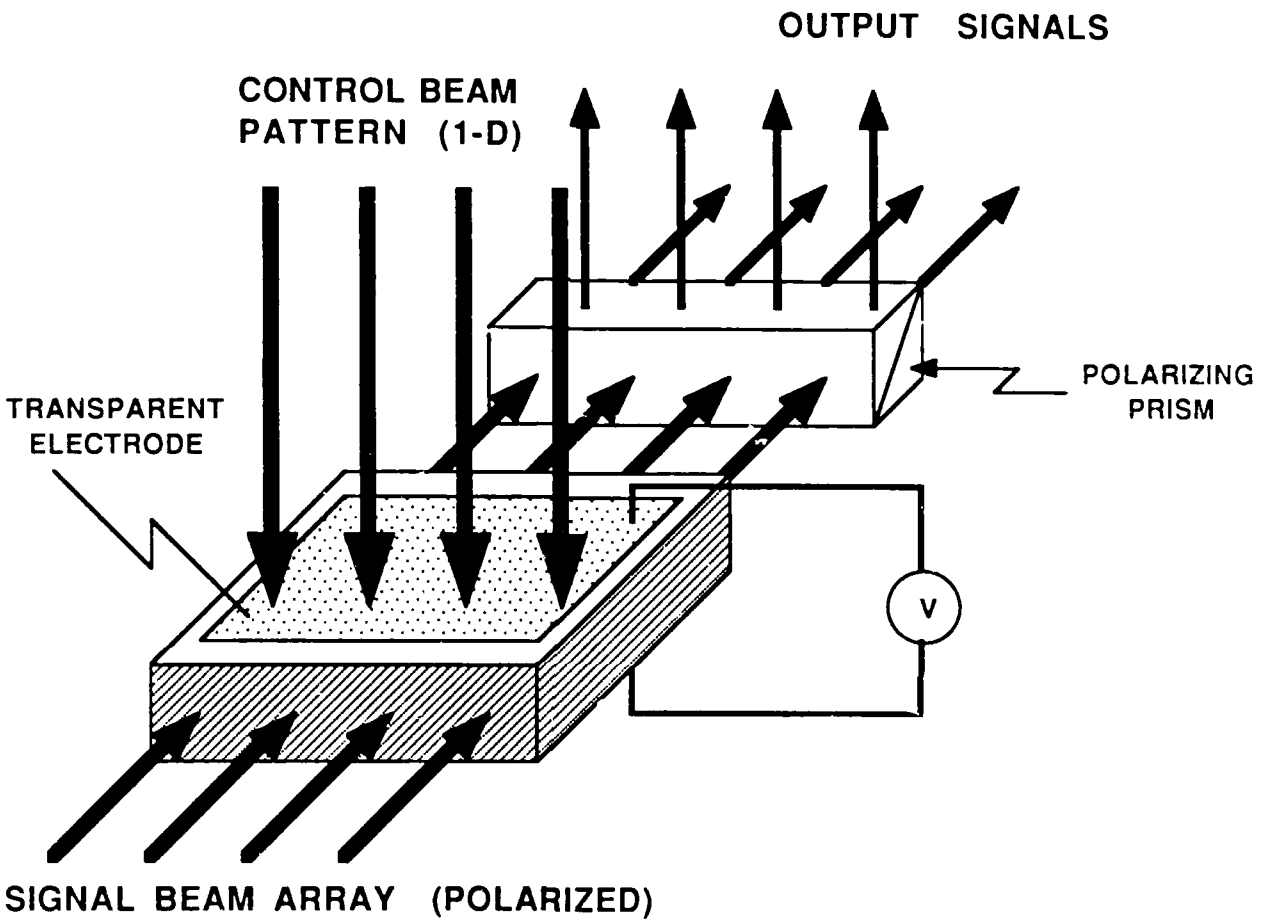
During the next year, this work will be expanded in two directions: Basic measurements to understand the dynamics of the charge and electric field patterns, and fabrication and evaluation of a linear array of optically controlled beam directors.

The electric field patterns inside the CdTe can be measured by observing the electrooptic birefringence using a measuring wavelength which does not create photo charge. The 1.5 μm HeNe laser should be adequate in this application. The light transmitted through the CdTe and the crossed analyzer can be viewed by a CCD camera and a video monitor. The data can be analyzed using a frame grabber and a PC. Using this technique, the electric field patterns will be measured at several applied voltage and control beam intensities.

From our earlier measurements, it appears that the optimum control wavelength may be between 0.85 and 0.95 μm. This range of wavelengths should give adequate photo charge which is approximately uniformly distributed throughout the material. Using a filtered incoherent incandescent source measurements of the field shielding will be made in this wavelength range.

A linear array of optical beam directors or optical switches can be fabricated as suggested in Figure 5. We plan to fabricate such an array and to evaluate its potential. This array can be used as a linear phase or amplitude spatial light modulator, as an optically controlled array of beam directors, and can be used to convert an incoherent linear infrared image into a coherent infrared image.

The switching device shown in Figure 1 can have wider potential application if some optical feedback can be incorporated. For example including a resonance at the control wavelength can create a thresh-holding optical element with a steep transmission vs. input intensity curve. Including a resonance at the signal wavelength can produce a bistable element. This effect will be investigated.



ONE DIMENSIONAL RECONFIGURABLE OPTICAL INTERCONNECTS

FIGURE 5

To date, there have been reports only on saturable absorber systems with fast response (~ nsec) and low $X^{(3)}$, or slow response (msec) and high $X^{(3)}$. We are examining the possibility of an organic system with characteristics between these two extremes, i.e., μsec response time.

Conducting polymers are another class of organic which show promise for nonlinear optical applications. The source of the $X^{(3)}$ in these materials is the nonlinear response of the charge carriers to the applied optical field. The maximum $X^{(3)}$ obtained from such a system is $\sim 10^{-9}$ esu, which is rather low. We are currently collaborating with researchers in the Chemistry Department who have considerable experience in the synthesis of conducting polymers. Our new Nd-YAG laser will allow us to make measurements of $X^{(3)}$ in such polymers using both DFWM and third harmonic generation.

Finally, we consider the application of organic materials to the charge-separation type of device discussed earlier. For example, if a polarization switch would be realized using MNA rather than CdTe, a great improvement in performance would be obtained. At first sight, this would appear to require charge transport and trapping in the MNA, which has not been demonstrated. However, this could be overcome by incorporating the MNA into a semiconductor structure in which the field is altered by electron-hole pair generation.

An even greater electro-optic coefficient would obviously be of benefit, and to this end, our collaboration with the Chemistry Department will also entail the characterization of $X^{(2)}$ in molecules. It is planned to incorporate these molecules into polymers in an aligned fashion using poling techniques. Measurement of $X^{(2)}$ using second harmonic generation would then be possible using the YAG laser.

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